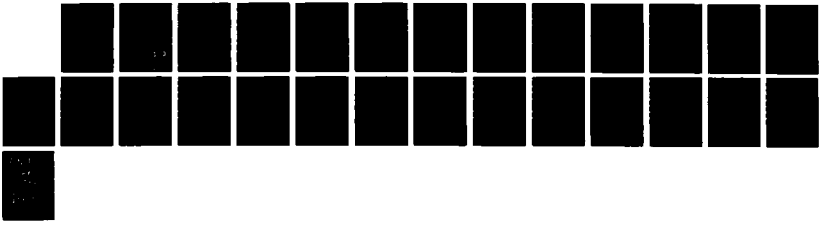
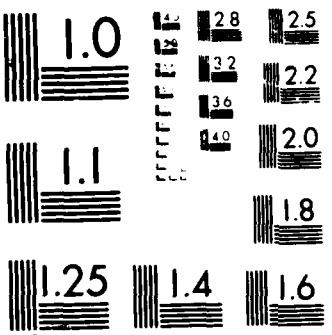
AD-A187 092 REVIEW OF WINOGRAD AND FLORES' UNDERSTANDING COMPUTERS AND COGNITION: A FAVORABLE INTERPRETATION(U) STANFORD UNIV CA KNOWLEDGE SYSTEMS LAB W J CLANCEY JUL 86 1/1

UNCLASSIFIED KSL-86-86-40 F/G 12/5




1.0
1.1
1.25
1.4
1.6
1.8
2.0
2.2
2.5
2.8
3.2
3.6
4.0

DTIC FILE COPY

July 1986

Report No. STAN-CS-87-1173
Also numbered KSL-86-48

(4)

AD-A187 092

Review of Winograd and Flores' Understanding Computers and Cognition: A Favorable Interpretation

by

William J. Clancey

Department of Computer Science

Stanford University
Stanford, CA 94305

DTIC
ELECTE
DEC 1 4 1987
S D
H

DISTRIBUTION STATEMENT A
Approved for public release;
Distribution Unlimited

87 12 8 112

AD-A187092

SECURITY CLASSIFICATION OF THIS PAGE

REPORT DOCUMENTATION PAGE

1a. REPORT SECURITY CLASSIFICATION UNCLASSIFIED	1b. RESTRICTIVE MARKINGS
2a. SECURITY CLASSIFICATION AUTHORITY	3. DISTRIBUTION / AVAILABILITY OF REPORT APPROVED FOR PUBLIC RELEASE, DISTRIBUTION UNLIMITED
2b. DECLASSIFICATION / DOWNGRADING SCHEDULE	
4. PERFORMING ORGANIZATION REPORT NUMBER(S) STAN-CS-87-1173 or KSL-86-48	5. MONITORING ORGANIZATION REPORT NUMBER(S) ONR TECHNICAL REPORT # 21
6a. NAME OF PERFORMING ORGANIZATION STANFORD KNOWLEDGE SYSTEMS LABORATORY 6b. OFFICE SYMBOL (If applicable)	7a. NAME OF MONITORING ORGANIZATION PERSONNEL AND TRAINING RESEARCH PROGRAMS
6c. ADDRESS (City, State, and ZIP Code) COMPUTER SCIENCE DEPARTMENT 701 WELCH ROAD, BUILDING C PALO ALTO, CA 94304	7b. ADDRESS (City, State, and ZIP Code) OFFICE OF NAVAL RESEARCH (CODE 1142PT) 800 NORTH QUINCY STREET ARLINGTON, VA 22217-5000
8a. NAME OF FUNDING / SPONSORING ORGANIZATION 8b. OFFICE SYMBOL (If applicable)	9. PROCUREMENT INSTRUMENT IDENTIFICATION NUMBER N00014-85K-0305
8c. ADDRESS (City, State, and ZIP Code)	10. SOURCE OF FUNDING NUMBERS PROGRAM ELEMENT NO. 61153N; PROJECT NO. RR04206; TASK NO. ~~0C~~; WORK UNIT ACCESSION NO NR702-003

11. TITLE (Include Security Classification)
REVIEW OF WINOGRAD AND FLORES' UNDERSTANDING COMPUTERS AND COGNITION: A FAVORABLE INTERPRETATION

12. PERSONAL AUTHOR(S)
WILLIAM J. CLANCEY

13a. TYPE OF REPORT	13b. TIME COVERED	14. DATE OF REPORT (Year, Month, Day)	15. PAGE COUNT
TECHNICAL	FROM _____ TO _____	JULY 1986	24

16. SUPPLEMENTARY NOTATION
KSL #86-48; APPEARED IN THE JOURNAL OF ARTIFICIAL INTELLIGENCE, 31(2), 232-250, FEBRUARY 1987

17. COSATI CODES		
FIELD	GROUP	SUB-GROUP
05	09	

18. SUBJECT TERMS (Continue on reverse if necessary and identify by block number)
PHILOSOPHY, ARTIFICIAL INTELLIGENCE, KNOWLEDGE REPRESENTATION

19. ABSTRACT (Continue on reverse if necessary and identify by block number)

AI researchers and cognitive scientists commonly believe that thinking involves manipulating representations. Thinking involves search, inference, and making choices. This is how we model reasoning and what goes on in the brain is similar. Winograd and Flores present a radically different view. They claim that our knowledge is not represented in the brain at all, but rather consists of an unformalized shared background, from which we articulate representations in order to cope with new situations. In contrast, computer programs contain only pre-selected objects and properties, and there is no basis for moving beyond this initial formalization when breakdown occurs.

(Continued on next page)

20. DISTRIBUTION / AVAILABILITY OF ABSTRACT ☒ UNCLASSIFIED/UNLIMITED ☒ SAME AS RPT ☐ DTIC USERS	21. ABSTRACT SECURITY CLASSIFICATION UNCLASSIFIED
22a. NAME OF RESPONSIBLE INDIVIDUAL DR. SUSAN CHIPMAN	22b. TELEPHONE (Include Area Code) (202) 696-4318 22c. OFFICE SYMBOL ONR 1142PT

DD FORM 1473, 84 MAR 83 APR edition may be used until exhausted. All other editions are obsolete

SECURITY CLASSIFICATION OF THIS PAGE

19. Abstract Continued

Winograd and Flores provide convincing arguments with examples familiar to most AI researchers. However, they significantly understate the role of representation in mediating intelligent behavior, specifically in the process of reflection, when representations are generated prior to physical action. Furthermore, they do not consider the practical benefits of expert systems and the extent of what can be accomplished. Nevertheless, the book is crisp and stimulating. It should should make AI researchers more cautious about what they are doing, more aware of the nature of formalization, and more open to alternative views.

Review of Winograd and Flores' Understanding Computers and Cognition: A Favorable Interpretation

by

William J. Clancey

Stanford Knowledge Systems Laboratory
Department of Computer Science
701 Welch Road, Building C
Palo Alto, CA 94304

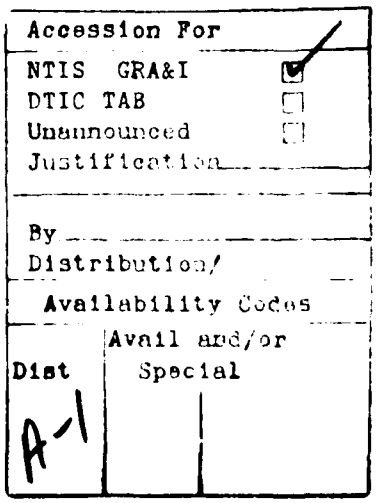
The studies reported here were supported (in part) by:

The Office of Naval Research
Personnel and Training Research Programs
Psychological Sciences Division
Contract No. N00014-85K-0305

The Josiah Macy, Jr. Foundation
Grant No. B852005
New York City

The views and conclusions contained in this document are the authors' and should not be interpreted as necessarily representing the official policies, either expressed or implied of the Office of Naval Research or the U.S. Government.

Approved for public release: distribution unlimited. Reproduction in whole or in part is permited for any purpose of the United States Government.



Understanding Computers and Cognition: A New Foundation for Design
Terry Winograd and Fernando Flores
Norword, NJ: Ablex Publishing Corporation, 1986
Bibliography, indices, 207 pps.

1. Introduction

> "Every triumphant theory passes through three stages: first it is dismissed as untrue; then it is rejected as contrary to religion; finally, it is accepted as dogma and each scientist claims that he had long appreciated the truth." (Gould, in *Ever Since Darwin*, quoting embryologist von Baer)

AI researchers and cognitive scientists commonly believe that thinking involves manipulating representations. For example, when we speak our thoughts are translated into words. We don't know what the mental operations are, but we assume that they are analogous to computer models of reasoning. There are hierarchical networks in the brain and stored associational links between concepts. There are propositions, implication rules, control processes, and so on. Thinking involves search, inference, and making choices. This is how we model reasoning, and what goes on in the brain is similar.

Winograd and Flores present a radically different view. In a nutshell, intelligence of the kind exhibited by people isn't possible by manipulating representations alone. In fact, they claim that our knowledge is not represented in the brain at all, at least not as stored facts and procedures. Many readers will reject this argument as obviously wrong, so obviously wrong they won't have to read the book to be convinced that it is just some variant of an Eastern religion or simply anti-scientific and not worth their time.

After reading the book twice and much consideration, I believe that Winograd and Flores are mostly right. We have the stuff here of Copernicus, Darwin, and Freud: At its heart, the human world is not what we thought. However, I believe that Winograd and Flores significantly understate the role of representation in mediating intelligent behavior, specifically in the process of reflection, when representations are generated prior to physical action. Furthermore, while the book convincingly describes the limitations of formal reasoning in the extreme, the practical extent of what can be accomplished is uncertain.

In understanding a book like this, it is useful to start with the problem that the authors are trying to address, that is, what they believe needs to be fixed. Winograd and Flores object to how computers are described in the popular literature, how AI researchers talk about intelligence, and the kinds of programs AI researchers, particularly in the area of Natural Language, are trying to develop. Winograd and Flores reject the commonly accepted beliefs that expert systems or any program could be intelligent, that representations can be used to model intelligent behavior, and that developing autonomous agents is an effective use for computers.

The book is based on the idea that understanding the nature of human cognition and what computers can do will enable us to use them more effectively. While many examples are given to illustrate limitations of current computer programs and to raise new possibilities, it is important to keep in mind that the authors have little interest in establishing what lies within practical bounds, that is, of what the representational paradigm will allow. For example, what expert systems might ultimately be able to do is not clear. The authors' philosophical stance places more value "in asking meaningful questions—ones that evoke an openness to new ways of being" not "in finding the 'right answers'" (page 13). Without a doubt, this book raises good questions.

Any attempt to summarize the arguments of this book in a few paragraphs is sure to raise many more questions than it answers. I will only present a few of the important terms and describe the general structure of the argument. In subsequent sections, I describe what I learned by reading the book and the problems that I perceive.

In general, Winograd and Flores approach cognition and computation in terms of what it means to "understand language in the way people do." Their analysis leads them to conclude that computers cannot understand natural language—not just now, never. This is because all programs—all representations, abstractions and primitives alike—are based on pre-selected objects and properties. The background that motivates representations, the experience behind the designer's analysis, has been cut out. Thus, when breakdowns occur, that is, when an inability to cope occurs because the demands for action placed upon the program are different from expected, there will be no basis for moving beyond the initial formalization. Yes, the designer can anticipate typical breakdowns and provide for representational change, but these will themselves be limited and prone to breakdown. The only way out is to generate new representations from outside the representational realm.

The key to this argument is that new representations spring from a shared, *unformalized background*. Coping with a breakdown involves articulating the basis of a representation. If you don't have this background, you can't speak with commitment, that is, with an implicit promise to clarify your meaning if questioned. Since you can't negotiate meaning, you can't engage in language.

According to Winograd and Flores, the view that we codify and store experiences in representations that exist is the brain is naive. Rather, representation is a post-hoc interpretation of history. What we articulate has meaning within a context, and what we say has been shaped historically by that context. But it is only formalized (represented) when we speak. We are not translating what we have already formalized.

The question naturally arises, just what are we storing in the brain? Perhaps we do not *store* anything? What is memory anyway? What are experiences? Surely we retain something. But perhaps we are not carrying around things in our heads? Consider how much we take for granted, in particular how our conception of objects and space shapes our conception of the mind, and how little we understand.

This book is anti-illusion, not anti-technology. It is not about what computers can't do (see Dreyfus) or shouldn't do (see Weizenbaum), but what they can do and how we should use them. It is primarily a positive statement, an insider's attempt to articulate AI practice, to understand what an AI researcher is doing when he writes a program. The goal is to understand how programs relate to life, what they capture of our nature, and what they leave out.

While the stated objective of the book is "how to design computer tools suited to human use and purposes," the authors are most interested in understanding what it means to be human (12). They believe that the rationalistic tradition, based on ideas such as internal representation, search, and choice among a set of alternatives, must be replaced if we are to understand human thought.

2. What the book is like

Understanding Computers and Cognition is intelligent, measured, and instructive. It deliberately avoids "philosophic scholarship" in order to focus on central points critical to developing a new understanding. In four introductory chapters, the authors describe the rationalistic tradition, hermeneutics, consensual domains, and speech act theory. The discussion is admirably crisp. In just fifty pages, the book relates subtle, unfamiliar philosophical, biological, and linguistic ideas to what AI researchers do everyday as programmers.

While a cursory scan shows the book to be full of jargon—thrownness, readiness-to-hand, shared background, blindness, breakdown, commitment—these words turn out to be useful for retaining the message. Like Freud's jargon (e.g., ego, subconscious), these terms introduce a new language for thinking about familiar things (40).

The book is also remarkable for sharp, definite statements that seem so contrary to common belief: "One cannot construct machines that either exhibit or successfully model intelligent

behavior." Amazingly, this comes from someone who gave us another book entitled, *Understanding Natural Language*. A "born again" conviction might lie behind the book's bold remarks.

An AI researcher who reads only the section on expert systems and does not take the time to seriously study the arguments is likely to be greatly alarmed by the inflammatory language: "Calling it intelligent might be useful for those trying to get research funding...." "The designers themselves are blind to the limits..."(93). In a few places the polemic becomes obscure and is easily dismissed: "World as the background of obviousness is manifest in our everyday dealings as the familiarity that pervades our situation, and every possible utterance presupposes this" (58). But with rare exception, the jargon and original point of view combine in clear and thought-provoking observations: "In trying to understand a tradition, the first thing we must become aware of is how it is concealed by its obviousness" (7). Almost every page has an idea worth underlining.

Sometimes the book has a poetic, mystical tone: "... (We) present the main points, listening for their relevance to our own concerns." The authors evoke reverence for their ideas, reflected by the book's final sentence: "The transformation we are concerned with is not a technical one, but a continuing evolution of how we understand our surroundings and ourselves—of how we continue becoming the beings that we are" (179). This is a book of religious philosophy, an inquiry into the origin of beliefs, values, and practices, of their nature, why they work, why they fail, and how they change. To quickly dismiss this book on technical grounds is to miss much more than the authors' conclusions about cognition.

If you are committed to understanding the book, I encourage reading the introduction (Chapter 1), then skipping around in whatever order appeals to you. Chapters 6 and 8 are excellent reviews; you could start there and then go forwards for the detailed discussion. Or if you prefer to start with the familiar, work backwards from the final chapter (which gives a good example of program design) to Chapter 10 (on current directions in AI) and the discussion in Chapters 7, 8, and 9 (on representation and language). However, I think that the book *must* be read completely to be accepted, and I found that reading it twice, separated by more than a year, was valuable.

3. Important ideas

Well into my second reading, I realized that somebody was wrong in a big way and I kept stopping in amazement at the possibilities. Could it be that Winograd and Flores are mostly wrong? What a grand embarrassment! From the other perspective, it's equally amazing how many researchers will respond with staunch certainty, "That's not right. Computers will do whatever we program them to do." Now I've accepted the main argument and have settled down to musing over details. I still think many people will just shake their heads and go about their business.

On first reading, the idea that seemed most important was that the computer should be thought of as a medium for communication, rather than an autonomous agent. A computer does not understand, it is exhibiting my commitments remotely. It is not the computer that makes requests or promises, but the programmer. The computer shows my patterns, my associations, my preferences.

This view increases my sense of responsibility and gratification. It is my work after all, not somebody else printing things on the screen. This also leads to an interesting question: How should I project myself? What should I put on the screen to reflect my choices? But after a year, I don't think the "computer as a medium" idea has changed what I do, just my theoretical understanding of what I am doing. After all, I always felt embarrassed or proud about my programs. I always knew that the computer was just showing my own constructions (or that of fellow programmers).

On second reading, a completely different message hit me. I realized that I don't have any patterns, associations, or preferences stored in my mind. This is a somewhat depressing and confusing thought. As Winograd and Flores indicate, the implications are more than technical,

relating to our image of what a person is, and this can influence our response to the argument. But the new conception is useful, and after awhile it starts to make sense. To illustrate this, in the following sections I summarize the ideas that I find particularly exciting by quoting from and paraphrasing the book. I amplify these ideas by discussing other connections and research implications.

3.1. All behavior proceeds from the subconscious

"To exist historically means that knowledge of oneself can never be complete" (33).

Language is necessarily blind to its context because it involves a formalization based on the *historical* structure of interactions. "As carriers of a tradition, we cannot be objective observers of it. Continuing work to revealing a tradition is at the same time a source of concealment" (179). Language crystallizes what we are, but it is always partial, biased, and momentary. The power of language is to articulate recurrence, to identify patterns, to claim structure, to explain. But it is always post hoc and apart from our being.

While these ideas may sound strange, most people are familiar with the idea that some behavior (at least) proceeds subconsciously, that is, not from articulated beliefs. This is the Freudian view of the subconscious: We act without knowing our own motivations. We do not always act rationally, by choice. Winograd and Flores take this to the extreme: All behavior is direct, without intervening representation.

In the popular understanding of psychiatric problems, subconsciously-directed behavior is associated with illness. We associate the subconscious with unusual, unhealthy behavior because the subconscious only becomes important to us when a breakdown occurs: a failure of a commitment, a violated expectation, a frustrated desire. When we perceive that we are apart from the world or when our actions are confused, this is when we use language to articulate what lies behind our behavior and our discomfort. We try to spell out what is not obvious, the assumed background that is affecting our behavior or our emotions.

In the "talking cure" of psychotherapy, a person articulates the recurrent structure in his behavior, naming situations and responses to them. Thus, he may become aware of the structural coupling in his life, allowing a new interpretation and new behavior. In this way, Freudian psychology has been reinterpreted as a form of hermeneutics: "The mental self is a story whose meaning is only interpretable in my life's history" (Wilber in *The Holographic Paradigm*, 276).

3.2. We are always already interpreting

In one of the most powerful ideas in the book, Winograd and Flores tell us that we are always attending, always selecting. To understand the value of this conception, consider the problem of explaining how we happen to attend to something. Suppose that I walk into a museum and see something interesting and walk over to study it. How did I know that it was interesting? What little clue made me decide to attend to it and to realize that it was interesting? What littler clue made me notice the first clue? Maybe the frame showed me where to look, but when did I decide to decide to notice that frame? In the museum I am always attending, always making interpretations. I am not matching preconceptions and recognizing value, as if they pre-existed as symbols in my head.

Following our practice in naming objects and properties around us, we place things in the mind: memories, symbols, patterns. We say: "Something gets recognized." There is an objective something in the world; there is a pattern being searched for in the brain; there is a matching process. Instead, Winograd and Flores tell us, there are just interpretations. There are no preconceived representations, no matching process. Instead, there is a "pre-orientation." "We are always already oriented to a certain direction of possibilities" (147).

Similarly, in psychiatric analysis, the idea of a symbol is used as if it were something that resides in the head. But to say that "X symbolizes Y for person P" is only to say that P responds to X *as if* it were Y. In a historical interpretation of behavior, we note a pattern and

explain it by this association. There need be no translation, no "symbol mapping rules."

The point is more stark than it might first appear. The argument leaves no room for saying that representations are perhaps "compiled," and this is why we have no conscious awareness of translating from representations to words. Rather we are not making decisions at all: *We have no choice, we are simply acting*. There are no "things stored in the brain" that we are searching or selecting between: "... the breakdown of a representation and jump to a new one happens independently of our will, as part of our coupling to the world we inhabit" (99).

3.3. All reasoning involves reinterpretation

Another perspective on "direct action," or what Winograd and Flores following Heidegger call "readiness-to-hand," is that all intelligent reasoning is reinterpretation. This is far more advantageous than acting according to pre-conceived representations, and only finding out later that they are wrong. Yes, we make mistakes because we act inappropriately, but we are not following "plans." There is extreme plasticity in our behavior. Every action is an interpretation of the current situation, based on the entire history of our interactions. In some sense every action is automatically an inductive, adjusted process.

As an example of this phenomenon, close your eyes and consider how many windows are in your bedroom. Did you visualize the process of moving around your room? Possibly we are reactivating a motoric sequence, simulating that we are actually in the room and moving about. We replay the history and articulate what we would see. But we are not necessarily remembering a particular walk through the room. We are constructing a coherent story, which is implicitly a generalization of our experience because it is based on all of our experience. We chain together a sequence of impressions and pretend that they occurred together. In this way, the chains of association are constructed freshly each time, as a reinterpretation of the unformalized background.

A functional simulation of the cognitive system in terms of manipulated representations cannot generate the range of reinterpretation an unformalized background allows. Winograd and Flores conclude, following Searle, that manipulating a representation formally is not understanding. Certainly there are formal games which we understand how to play. We can even accomplish our goals by playing formal games. But as soon as the interaction changes from the previous history, breakdown occurs, and a reinterpretation in language is required. We engage in a dialogue that articulates the basis of a representation and adjusts it to a new situation. To understand is to be able to make the commitment to do this reinterpretation.

3.4. We assume commitment in other people

As Weizenbaum pointed out about ELIZA, it is amazing that we are so convinced by so little and that we assume so much. Even when you are told how little ELIZA, SHRDLU, and MYCIN know, it still strains the imagination to appreciate the magnitude of their ignorance. We are all like children preferring to believe that the fantasy is real. Indeed, we don't have to "suspend disbelief" (in the theatrical sense), this is how cognition normally works: Attributing meaningfulness and assuming commitment go hand and hand. The situation is insidiousness: We don't normally articulate shared background, and computers don't have any. It plays right into our assumptions. If you use my words, I assume that you know what I mean. If you say you believe something, I assume that you are ready to convince me.

Weizenbaum stressed the lack of responsibility of computers because they are not part of the social fabric. The argument here is stronger: Computers cannot be responsible because they cannot even form commitments. When I speak with commitment I do more than just mouth words. I do not pretend. I am ready to defend what I say. I am committed. To speak the truth means to be willing and able to articulate why you believe it.

In providing explanations, we must determine why breakdown occurred. What is not obvious, not part of the shared background? What must be articulated? In constructing explanation programs, I have often concluded that we have not placed enough of the burden on the person asking the question. Unless there are systematic surprises that the explainer might guess, the

questioner must articulate the nature of his surprise. The explainer must then be ready to form an interpretation that is contrary to his own point of view. However, we cannot completely model how a system's activity will perturb the interaction between user and machine. We can't anticipate every user's interpretations of what the machine is doing (53). Given these limitations, we might focus instead on opening up the program's representations so they are easily browsed, making it easy for the questioner to figure out what he needs to know on his own.

Winograd and Flores provide an intriguing discussion of how computers might be best suited as coordinators of commitments, "the essential dimension of collective work." Following from their analysis of language, they propose that a program keep track of what we have to do, recording the status of our active commitments. Their proposal broadens our awareness from that of the individual working alone at a personal workstation to the social dimension of what is being written, computed, or recorded (158). This idea is likely to have widespread appeal and could significantly enhance how we use computers.

3.5. People do not carry models around in their heads

Cognitive models explain patterns of behavior; they are developed by scientists. It is a strange and tremendous leap to say that these models actually exist in the heads of the people being modeled. While we commonly say that a person has knowledge, knowledge is not something that you can possess like an object. Knowledge is always an individual interpretation within a shared background. It is neither subjective, nor objective (75). To say that someone knows something is not to say that he is in a certain state, but to explain his behavior over a sequence of interactions and to claim that he is predisposed to act in a similar way in similar situations (47).

Few people believe that when we ride a bicycle we are manipulating internal representations of the handlebars and pedals, modeling their location internally, and computing trajectories. According to Winograd and Flores, speech is the same, a kind of skill coupled to the environment. While we may *symbolize our utterances on paper* in some calculus or written notation, there is nothing corresponding to these notations in the brain.

This has significant implications for understanding expert behavior. We are not modeling objects that exist inside an expert's head. This explains what is so patently obvious when you work with experts, namely that they have so much difficulty laying out consistent networks and describing relations among concepts in a principled way. If experts knew causal and subsumption networks as discrete concepts and relations, why would we find it so difficult to extract these statements from them? The concepts are often not defined, let alone related in a fixed, systematic way to one another. Experts know how to behave and they know formalizations that model how they behave.

The evidence in student modeling research is similar. Brown and VanLehn found that student errors in subtraction, modeled as bugs in the procedure followed by students, changed over time. They called this "bug migration" and sought a systematic explanation for why the bugs changed. The key is that there never was a bug in the student's head. When you realize this, you realize that you don't have to explain why the students *decided* that one procedure was wrong and another was better. This does not mean that there is no pattern to be found. Winograd and Flores would say that there is a mechanistic argument, it just isn't based on manipulating a representation.

This analysis might lead to an entirely different teaching method: not isolating the bug, but establishing an appropriate coupling and forcing breakdown. However, we still need to understand what articulation does to behavior. For example, in physical skills, such as playing the piano, attending directly to a faulty action—actually feeling that you are making it happen—allows you to get a grasp on the behavior and change it. The role of language in isolating where an undesirable action occurs automatically is perhaps similar, again, the possible value of psychoanalysis.

By this model, the most effective training occurs on the job site, hence the instructional

strategy of getting the students to the workplace and minimizing the classroom blabber. Winograd and Flores' analysis provides a subtler understanding: Teaching involves establishing the history of interaction that constitutes a background that will lead to useful interpretations. Establishing a "structural coupling" means experiencing this history of interactions, not just being told what you would do if you had gone through the process. The problem is familiar: You don't understand me because you don't know where I've been. If all intelligent behavior flows from the unformalized background, teaching how to behave by saying what to do can only provide patterns to follow by rote. You have to try it yourself and get the feel of it. Thus, the repeated teacher's fallback, "You'll know better what I mean when you get out there."

While the implications for instructional computing are not clear, it seems at least theoretically important to realize that there is a difference between solving a problem and articulating a model (rationalizing the solution sequence). We knew this already, but Winograd and Flores provide a theoretical foundation for building up a new understanding, so we can view the inability to articulate a model as not a lack of self-knowledge, but the normal state of affairs.

3.6. Engineering develops from recurrent breakdown

Understanding and anticipating failure (breakdown) is at the heart of engineering. Essentially, Winograd and Flores have provided a theoretical background for understanding how programming, especially knowledge engineering, is like structural engineering. Programs don't always do what we expect because the designer did not anticipate how users would interact with the program and interpret its actions. A large part of this book concerns how programmers must anticipate the demands of the environment and prepare programs to cope with breakdown.

As in structural engineering, what makes knowledge engineering possible is that breakdowns recur. These patterns lead the engineer to formulate "objective distinctions." Essentially what we take to be objective truth is what many people have articulated over a long period of time and we as observers expect to continue in the future.

However, constructing an autonomous agent is much more difficult than typical engineering problems. It is like building a bridge that will change its own structure as its interaction with the environment changes. This is the idea of an autopoietic system: It maintains its functions. This theory was developed in biology, and living organisms are the best examples we have. The idea now arises in computer systems engineering and plays an important role in the design of satellites and planetary probes.

A crucial point is that the organism adapts to meet the demands of its interactions. But this is not a process of representing the world: "The demands of continued autopoiesis shape this structure in a way that can be viewed as a reflection of a external world. But the correspondence is not one in which the form of the world is somehow mapped onto the structure of the organism" (62).

3.7. Systematic domains admit to formal representation

Systematic domains are those in which there is a great regularity in relations over time and among people, so that there appears to be objective knowledge (172). In modeling intelligent behavior within a systematic domain, we don't and needn't necessarily (indeed, can't) represent the meaning of terms. Rather we represent their systematic role within a network of requests and promises. Indeed, the operation of a program does not require that it represents anything at all. It's all in the eye of the beholder, who interprets input and output in terms of a systematic mapping in his world (86). When MYCIN says the word "culture," you interpret it as something objective that you know about.

This analysis provides a fascinating handle on the nature of language, models, and formalization. It helps us understand why programs work as well as they do and what can go wrong. Thus, we can better understand what we are doing and perhaps how to go about it more systematically.

A surprising conclusion is that the Winograd and Flores analysis [illegible] approach to knowledge representation. In short, the very nature of models is [illegible] our observations, the world as we know it, in terms of objects and properties. [illegible] representation methods are designed to attack this problem systematically.

The idea of systematic domains may also encourage us to adopt a [illegible] knowledge acquisition. The task is to get at what's regular recurrent. For example, in an interactive dialogue system, say a teaching program like GUIDON, we formalize the recurrent conversations that occur between a student and teacher. The idea of recurrence is very powerful for understanding what representation is all about.

Perhaps most important, Winograd and Flores lead us to see objects, properties, and relations as the essence of what a representation is, not just the present-day state of the art in AI research. We can never represent the meaning of terms. And because representation is a formalization process, we should use a logic-based approach, not because it's the solution to modeling intelligent behavior, but because it's precisely what we can do on computers. Formalization is what we're doing anyway, so we might as well be rigorous about it.

The idea that language arises in the need to action also fits very well with our experience in constructing programs. The relevant properties of a representation change as it is interpreted for different purposes such as problem solving, explanation, and cognitive modeling. For example, converting MYCIN to a hypothesize-and-test program required distinguishing between data and hypothesis "parameters" and classifying them. Similarly, an explanation program requires propositions in control rules to be classified as static and dynamic. A student modeling program needs to have control rules classified according to the constraints they satisfy. Thus, we build up representational structures according to the distinctions that are important for operating upon them. "Grounding of descriptions in action pervades *all* linguistic structure of objects, properties, and events" (17).

The ideas of systematic domains and recurrent back-ground have tremendous importance for knowledge engineering. For example, as we move from representing high-level patterns to representing generative theories for why these patterns occur, we must realize that this might not be possible in all cases.

For example, generating NEOMYCIN's control rules for diagnosis from more primitive concepts is probably impossible because they are based on a huge social context. Certainly, we could always generate a limited set of rules from more primitive concepts, and this might worthwhile if the diagnostic procedure is relatively stable. But we must keep in mind that the primitives we choose are in an important sense ad hoc. The game can continue for several levels, but we can never get below the representation to something fixed and final. We will always have to assume a set of axioms. Of course, mathematicians have had to face this, and we should not have expected the formalization of medicine or other domains to be any different.

4. Unanswered Questions

"One cannot construct machines that either exhibit or successfully model intelligent behavior" (11).

Winograd and Flores have chosen an uncompromising point of view about the nature of intelligence. Their definition contradicts the commonly accepted view that computer programs "which exhibit behavior we call 'intelligent behavior' when we observe it in human beings" are intelligent (Feigenbaum and Feldman, *Computers and Thought*). Even if a computer program consistently wins games of chess, Winograd and Flores would say that this is not intelligence. This restrictive view is unfortunate, because it greatly complicates the problem of understanding this book.

All models are approximate and selective. Engineering models are successful within some practical setting. Rather than insisting that "computers cannot diagnose diseases," for example, which violates common sense, it would be more useful to carefully articulate when the models will fail. Little is gained by saying that such programs are not models of intelligent behavior.

While the book has clear implications for research in Natural Language and instructional research, as I have described, it is unclear just how well computer models might eventually perform in systematic domains. That is, how well can we circumscribe domains to construct useful and effective representations? Is it of any practical value to say that commitment and hence language cannot exist in a systematic domain (where the importance of unformalized background is minimized)? Is the shared background of people as great as Winograd and Flores suggest when they exclude computers from participating in language? When breakdown occurs, just how well do people resolve it? In this section I consider ways in which the arguments in the book appear to be incomplete and perhaps distort the nature of cognition.

4.1. What is the mechanism of memory?

To recapitulate, conceptual structures are not stored in the brain; the concepts of our language do not organize our memory. There are no stored associations, no conceptual network. Instead, we act: We speak, we associate. We don't do this by interpreting a network that mirrors the conceptual structure in what we say. Rather, the history of our behavior may exhibit recurrence that we can represent as such a network.

We are left with the image of some amorphous blob that speaks. How can we explain recurrence, if there no structural predisposition to associate concepts in some way? Winograd and Flores believe that there is some mechanism behind jumps to new representations, but they provide no description of what it might be. They make no attempt to reinterpret models of memory and learning according to their theory.

For example, what accounts for our tendency to remember exceptions (as described by Schank)? Winograd and Flores acknowledge that Schank's work and ideas like "default reasoning" are closer to the nature of cognition, but they insist that these approaches are still limited by the need to distinguish the relevant objects and properties before doing any representation (116).

Is there any evidence of a mechanism that generates the recurrence in our behavior? What about timing experiments involving discrimination and recall? Winograd and Flores claim that these experiments do not deal with "meaningful material" (114). But aren't hierarchical relations meaningful? Couldn't systematicity in abstraction, for example the patterns in levels of "natural kinds," be explained by structural properties of memory? The problem is that any admission of structure in the brain corresponding to conceptual relations undermines the argument that representations do not exist in the brain.

It appears obvious that the way the brain works favors categorization and association of certain kinds. From here it is but a short step to hierarchical search. Perhaps Winograd and Flores (and Maturana) have got the main idea right, that we aren't *examining* representations internally, but they have woefully ignored the problem of explaining recurrence in memory. It would have been helpful if the book included an appendix that at least acknowledged opposing arguments (such as Fodor's *The Language of Thought*).

4.2. How much background is shared?

"If a lion could talk, we could not understand him." (Wittgenstein, *Philosophical Investigations*)

According to Winograd and Flores, language requires being able to commit to articulating a shared background. If no common ground is found, then breakdown is not resolved. But the book seems to understate the difficulty of resolving breakdown. Isn't the normal state of affairs one in which individuals (and countries) frequently do not understand each other? We get by normally by making many assumptions and by ignoring differences. Perhaps resolving specific differences is not as important as sharing the goal to "work something out."

A few social rules (part of shared background) for coping with unresolved breakdown may be more important than having the shared background to resolve specific differences. Obviously, not much communication could occur on the basis of just agreeing to disagree. However, the

book seems to adopt the opposite stance of idealizing language, suggesting that most breakdowns are resolved in the specific elements of shared background. The general agreement to adapt and cope with ambiguity and unresolved differences could be more important.

The book's idealized description of language is clear when we consider our interactions with animals and children. Shared background is minimized here, but communication is possible. It isn't necessary to be "fully human" to engage in language. Even if computers are programmed to be part of the social structure, even if they are our slaves, interaction with them can be consensual. Their speech acts can create commitment, just as much as a dog can request to play and then become engaged in a game of mock attack or chasing. Certainly there will be practical limitations, as we may not always understand a chimpanzee, and the differences between a dog's bark to play, to eat, or to warn may be too subtle for anyone but his master to discern. However, of what practical value is it to so narrowly define language and intelligence as to rule out the behavior of animals because they are not "fully human"? It is good to make people more aware of the social dimensions of language, but Winograd and Flores have adopted an almost religious point of view that may overstate the requirements of shared background and the extent to which breakdown is typically resolved.

4.3. What are the practical limits of formalization?

The book states that we are "now witnessing a major breakdown in the design of computer technology" (78). No evidence for this observation is given; just the inverse seems to be true. We are witnessing a major recognition of how much human knowledge is regular and can be usefully formalized. In the rapid growth of expert systems applications, engineers in particular are realizing the value of qualitative modeling techniques for describing recurrent objects, properties, and relations. Possibly there has been a misinterpretation of what computers are doing and the nature of intelligence, but the payoff is on the upswing and the limits appear to be years away, at least.

The book provides very little basis for determining the practical limits of formalization, particularly for applications of Artificial Intelligence to science and engineering. Perhaps by continuing to find structure within structure we can get programs that are very good, and even fool most people. Yes, they will fail sometimes, but so do people. There is little evidence that the practical limitations of formal reasoning are as serious as the book suggests.

Practical implications of the argument tend to return to conclusions we already knew, as I indicated in briefly considering explanation, teaching, and knowledge acquisition. However, the book gives us an improved understanding of what is difficult and why we might not succeed. The most important change might be a better understanding of what we are doing.

4.4. Isn't reflection an essential part of reasoning?

"Human cognition includes the use of representations, but is not based on representation." "Experts do not need to have formalized representations in order to act. They may at times manipulate representations as one part of successful activity, but it is fruitless to search for a full formalization of the pre-understanding that underlies all thought and action" (99). "The essence of our intelligence is our thrownness, not our reflection."

I believe that this book significantly understates the importance of reflection, to the point of distorting the nature of cognition. In reflection, we articulate our background in order to compare possible behaviors, anticipate consequences, and plan, rather than acting impulsively. Even granting the nature of unformalized background, readiness-to-hand, and the immediate nature of reflection (we don't decide to reflect), the valued action in a consensual domain is one that anticipates ramifications. Human reasoning is immensely more successful by our ability to simulate what might happen, to visualize possible outcomes and prepare for them. We do this by reflecting, saying what we expect, and responding to what we say. (An excellent description of this imagination process appears in Jaynes's *Bicameral Mind*.)

We create representations by language, by acting. We make interpretations by what we say. Every representation is an interpretation. But isn't every representation therefore potentially

crucial in our action? Granted that representations are not "inside" and that they are blind, once articulated don't they play a central role in intelligent behavior? We are always reinterpreting old representations. We are not just speaking like birds singing. The articulation is essential, it can change our behavior. Winograd and Flores fail to properly emphasize the loop: We are always listening to ourselves. Even if representations are not directly generated from representations, they are generated *in response to* representations. In particular, imagery and silent utterances are a form of "*mental representation*" which is part of the cognitive system. While these representations may be unnecessary for behavior, much behavior is mediated by them.

The weakness of the argument minimizing the centrality of representation is seen clearly in the example of the chairman who is always directly acting (34). Winograd and Flores greatly understate the importance of making observations, forming hypotheses, and consciously choosing a course of action. In chairing a meeting, I attend, stop myself from saying something (anticipating a reaction), plan things to say, arrange a list of people to call upon, attempt to weigh alternative topics, watch the time, and suggest a revised agenda. The book seems to overgeneralize the nature of physical skills—as provided by the example of a hammer and how we attend to it—in suggesting that cognitive behavior generally has the same degree of automaticity and lack of reflection. Granted behavior must be immediate; there is no homunculus inside interpreting representations. But forming representations and reinterpreting them is where all of the action is! Cognitive behavior is strongly coupled to the representations it creates; as visualizations and silent utterances, they are "inside" the system as much as anything else.

Most of my day involves an inner conversation. Most of my awake activity is a long sequence of telling and asking statements to myself. Granted, I don't know where the questions come from (I don't have to work at firing neurons). Granted, I don't know where the answers come from. I just keep making requests and promises to myself. "What are all of the projects I'm working on now? I have to call Jan. What will I do when I finish this? I'll work on the review tomorrow. Where is my yellow pad?" Most of my life seems to involve responding to my own language, the representations I generate.

Winograd and Flores appear to have gotten the emphasis wrong. In emphasizing that TELL and ASK actions do not come from interpreted representations, they ignore the crucial point that thinking involves the generation of representations and attending to them. We are constantly observers to our own thinking behavior. We are constantly responding to representations.

Most important, we tell ourselves what we *might do*. Then we react to this. And in our reaction we promise ourselves that we will do something different or make a request. We do not just simply act. We are engaged in a loop of imagining action and visualizing consequences. Yes, our words and motoric actions always proceed directly, but often not before intervening representational actions and sometimes not at all without them.

How then do we get to the state of reflecting? What, after all, changes us? Perhaps reflection is built in? Being able to place ourselves in a situation so we can know how we might behave is incredibly powerful. It means being able to simulate a structural coupling, to know what we are apt to do. This is much more than articulating a background; it is articulating the behavior that the background will elicit. By projecting forward in this way, admittedly with uncertainty, we can anticipate the consequences of behavior. This anticipation then has the potential of changing our background and resultant behavior.

By overemphasizing the direct, ready-to-hand, unreflective core of all behavior (including reflection itself), Winograd and Flores understate the importance of representation in intelligent behavior. That an expert can act without a representation is not very interesting in comparison to how impoverished his behavior would be if representations were not available for solving the difficult problems.

5. Recommendations

This book should make AI researchers more cautious about what they are doing, more aware of the nature of formalization, and more open to alternative views. By addressing the nature of representation and reasoning with examples familiar to most AI researchers, the book has the potential of being more influential than other criticisms of the field.

A scientific enterprise requires openness to blindness of all kinds. This book explains why blindness is inevitable and elevates our awareness of the origin of language and how breakdowns occur. When the Chenobyls and Challengers of AI occur, we can look back at this book to better understand why our programs failed. The book provides an important theoretical basis for the analysis of failure in knowledge engineering. Indirectly it tells us how to analyze domains: What are the recurrent dialogues? What breakdowns occur? What are the expert's methods for coping with breakdown? What are the shared sources of experience? Who can talk to whom and why?

Every AI researcher should read this book. Designers of interactive programs interested in theoretical aspects of language and improving their understanding of what they are doing will find this book to be fascinating, engrossing, and obstinately provocative. The title is apt: If you are interested in understanding what computers can do, for example how you might use them in your business, and have a philosophical bent, you should definitely read this book. However, be forewarned that it points the way, rather than providing answers.

The authors state that the book is not intended to be a scholarly treatise, and it was probably a good idea to simplify the presentation in this way. However, I think the book will mostly appeal to researchers and academicians, and these readers should be aware that there are other books that adopt similar points of view. For example, I learned about "readiness-to-hand" from reading Polanyi, who calls the idea "tacit knowledge" (using the same hammer example). Yet, Winograd and Flores do not cite Polanyi, and Polanyi does not cite Heidegger. The intellectual development of the ideas is therefore obscure. I believe that Richard Rorty's *Philosophy and the Mirror of Nature* (not cited by Winograd and Flores) is a good reference for readers who want a more complete understanding of the argument against the idea of internal representation. *Understanding Computers and Cognition* goes a long way towards making philosophical works like this more accessible to AI researchers.

In conclusion, even though the the book is extremely well-written, its arguments are so counterintuitive many readers are likely to remain confused and unconvinced. The book helps resolve foundational issues of AI, but the practical implications are unclear.

One goal for writing the book was to prevent a false view of computers from distorting our understanding of people. Ironically, the book's new view of cognition is a little scary, making reasoning seem limited and out of our personal control. The earth is not in the center; man is not in the center, and neither is his conscious mind. The relation of responsibility to reflection needs to be better developed and balanced against the core of automaticity that lies behind behavior. On the other hand, the book supports a humanist position, emphasizing our commonality, that what we are is mostly what we do together.

Certainly, this book might change how you think about the world. As I squashed a huge mosquito the other night, I thought, "So much for another structural coupling."

References

Brown, J. S. and VanLehn, K. 1980. Repair theory: A generative theory of bugs in procedural skills. *Cognitive Science*, 4(4):379-415.

Clancey, W. J. 1986. From Guidon to Neomycin and Heracles. *The AI Magazine*, August, 7(3):20-40.

Dreyfus, H. L. 1972. *What Computers Can't Do: A Critique of Artificial Reason.* New York: Harper and Row.

Feigenbaum, E.A. and Feldman, J. 1963. *Computers and Thought.* Malabar: Robert E. Krieger Publishing Company, Inc.

Fodor, J. A. 1975. *The Language of Thought.* Cambridge: Harvard University Press.

Gould, S. J. 1977. *Ever Since Darwin.* New York: W. W. Norton & Co.

Jaynes, J. 1976. *The Origins of Consciousness in the Breakdown of the Bicameral Mind.* Boston: Houghton-Mifflin.

Polanyi, M. 1967. *The Tacit Dimension.* Garden City: Anchor Books.

Pribram, K. H. 1977. *Languages of the Brain.* Monterey: Wadsworth Publishing Co.

Rorty, R. 1979. *Philosophy and the Mirror of Nature.* Princeton: Princeton Univeristy Press.

Schank, R. C. 1981. Failure-driven memory. *Cognition and Brain Theory,* 4(1):41-60.

Weizenbaum, J. 1976. *Computer Power and Human Reason: From Judgment to Calculation.* San Francisco: W.H. Freeman and Company.

Wilber, K. W. (editor) 1982. *The Holographic Paradigm and Other Paradoxes.* Boulder: Shambhala.

Winograd, T. 1972. *Understanding Natural Language.* New York: Academic Press.

Wittgenstein, L. 1958. *Philosophical Investigations.* New York: The Macmillan Company.

Personnel Analysis Division,
AF/MPXA
5C360, The Pentagon
Washington, DC 20330

Air Force Human Resources Lab
AFHRL/MPD
Brooks AFB, TX 78235

AFOSR,
Life Sciences Directorate
Bolling Air Force Base
Washington, DC 20332

Dr. Robert Ahlers
Code N711
Human Factors Laboratory
Naval Training Systems Center
Orlando, FL 32813

Dr. Ed Aiken
Navy Personnel R&D Center
San Diego, CA 92152-6800

Dr. William E. Alley
AFHRL/MOT
Brooks AFB, TX 78235

Dr. Earl A. Alluisi
HQ, AFHRL (AFSC)
Brooks AFB, TX 78235

Dr. John R. Anderson
Department of Psychology
Carnegie-Mellon University
Pittsburgh, PA 15213

Dr. Nancy S. Anderson
Department of Psychology
University of Maryland
College Park, MD 20742

Dr. Steve Andriole
George Mason University
School of Information
Technology & Engineering
4400 University Drive
Fairfax, VA 22030

Dr. John Annett
University of Warwick
Department of Psychology
Coventry CV4 7AJ
ENGLAND

Dr. Phipps Arabie
University of Illinois
Department of Psychology
603 E. Daniel St.
Champaign, IL 61820

Technical Director, ARI
5001 Eisenhower Avenue
Alexandria, VA 22333

Special Assistant for Projec
OASN(M&RA)
5D800, The Pentagon
Washington, DC 20350

Dr. Michael Atwood
ITT - Programming
1000 Oronoque Lane
Stratford, CT 06497

Dr. Patricia Baggett
University of Colorado
Department of Psychology
Box 345
Boulder, CO 80309

Dr. Eva L. Baker
UCLA Center for the Study
of Evaluation
145 Moore Hall
University of California
Los Angeles, CA 90024

Dr. James D. Baker
Director of Automation
Allen Corporation of America
401 Wythe Street
Alexandria, VA 22314

Dr. Meryl S. Baker
Navy Personnel R&D Center
San Diego, CA 92152-6800

Dr. Donald E. Bamber
Code 71
Navy Personnel R & D Center
San Diego, CA 92152-6800

Mr. J. Barber
HQS, Department of the Army
DAPE-ZBR
Washington, DC 20310

Capt. J. Jean Belanger
Training Development Division
Canadian Forces Training System
CFTSHQ, CFB Trenton
Astra, Ontario, K0K
CANADA

CDR Robert J. Biersner, USN
Naval Biodynamics Laboratory
P. O. Box 29407
New Orleans, LA 70189

Dr. Menucha Birenbaum
School of Education
Tel Aviv University
Tel Aviv, Ramat Aviv 69978
ISRAEL

Dr. Werner P. Birke
Personalstammamt der Bundeswehr
Kolner Strasse 262
D-5000 Koeln 90
FEDERAL REPUBLIC OF GERMANY

Dr. Gautam Biswas
Department of Computer Science
University of South Carolina
Columbia, SC 29208

Dr. John Black
College, Columbia Univ.
525 West 121st Street
New York, NY 10027

Dr. Arthur S. Blaiwes
Code N711
Naval Training Systems Center
Orlando, FL 32813

Dr. Robert Blanchard
Navy Personnel R&D Center
San Diego, CA 92152-6800

Dr. Jeff Bonar
Learning R&D Center
University of Pittsburgh
Pittsburgh, PA 15260

Dr. J. C. Boudreaux
Center for Manufacturing
Engineering
National Bureau of Standards
Gaithersburg, MD 20899

Dr. Gordon H. Bower
Department of Psychology
Stanford University
Stanford, CA 94306

Dr. Richard Braby
NTSC Code 10
Orlando, FL 32751

Dr. Robert Breaux
Code N-095R
Naval Training Systems Cente
Orlando, FL 32813

Dr. John S. Brown
XEROX Palo Alto Research
Center
3333 Coyote Road
Palo Alto, CA 94304

Dr. Bruce Buchanan
Computer Science Department
Stanford University
Stanford, CA 94305

Dr. Howard Burrows
National Institute of Health
Bldg. 10, Room 5C-106
Bethesda, MD 20892

Dr. Patricia A. Butler
OERI
555 New Jersey Ave., NW
Washington, DC 20208

Dr. Tom Cafferty
Dept. of Psychology
University of South Carolina
Columbia, SC 29208

Dr. Robert Calfee
School of Education
Stanford University
Stanford, CA 94305

Joanne Capper
Center for Research into Practice
1718 Connecticut Ave., N.W.
Washington, DC 20009

Dr. Jaime Carbonell
Carnegie-Mellon University
Department of Psychology
Pittsburgh, PA 15213

Mr. James W. Carey
Commandant (G-PTE)
U.S. Coast Guard
2100 Second Street, S.W.
Washington, DC 20593

Dr. Susan Carey
Harvard Graduate School of
Education
337 Gutman Library
Appian Way
Cambridge, MA 02138

Dr. Pat Carpenter
Carnegie-Mellon University
Department of Psychology
Pittsburgh, PA 15213

Prof. John W. Carr III
Department of Computer Science
Moore School of
Electrical Engineering
University of Pennsylvania
Philadelphia, PA 19104

Dr. Robert Carroll
OP 01B7
Washington, DC 20370

LCDR Robert Carter
Office of the Chief
of Naval Operations
OP-01B
Pentagon
Washington, DC 20350-2000

Dr. Fred Chang
Navy Personnel R&D Center
Code 51
San Diego, CA 92152-6800

Dr. Alphonse Chapanis
8415 Bellona Lane
Suite 210
Buxton Towers
Baltimore, MD 21204

Dr. Davida Charney
Department of Psychology
Carnegie-Mellon University
Schenley Park
Pittsburgh, PA 15213

Dr. Eugene Charniak
Brown University
Computer Science Department
Providence, RI 02912

Dr. Paul R. Chatelier
OUSDRE
Pentagon
Washington, DC 20350-2000

Dr. Michelene Chi
Learning R & D Center
University of Pittsburgh
3939 O'Hara Street
Pittsburgh, PA 15213

Mr. Raymond E. Christal
AFHRL/MOE
Brooks AFB, TX 78235

Dr. Yee-Yeen Chu
Perceptronics, Inc.
21111 Erwin Street
Woodland Hills, CA 91367-371

Dr. William Clancey
Stanford University
Knowledge Systems Laboratory
701 Welch Road, Bldg. C
Palo Alto, CA 94304

Chief of Naval Education
and Training
Liaison Office
Air Force Human Resource Lab
Operations Training Division
Williams AFB, AZ 85224

Assistant Chief of Staff
for Research, Development,
Test, and Evaluation
Naval Education and
Training Command (N-5)
NAS Pensacola, FL 32508

Dr. Allan M. Collins
Bolt Beranek & Newman, Inc.
50 Moulton Street
Cambridge, MA 02138

Dr. John J. Collins
Director, Field Research
Office, Orlando
NPRDC Liaison Officer
NTSC Orlando, FL 32813

Dr. Stanley Collyer
Office of Naval Technology
Code 222
800 N. Quincy Street
Arlington, VA 22217-5000

Dr. Lynn A. Cooper
Learning R&D Center
University of Pittsburgh
3939 O'Hara Street
Pittsburgh, PA 15213

Dr. Meredith P. Crawford
American Psychological Association
Office of Educational Affairs
1200 17th Street, N.W.
Washington, DC 20036

Dr. Hans Crombag
University of Leyden
Education Research Center
Boerhaavelaan 2
2334 EN Leyden
The NETHERLANDS

LT Judy Crookshanks
Chief of Naval Operations
OP-112G5
Washington, DC 20370-2000

Dr. Kenneth B. Cross
Anacapa Sciences, Inc.
P.O. Drawer Q
Santa Barbara, CA 93102

Dr. Mary Cross
Department of Education
Adult Literacy Initiative
Room 4145
400 Maryland Avenue, SW
Washington, DC 20202

CTB/McGraw-Hill Library
2500 Garden Road
Monterey, CA 93940

CAPT P. Michael Curran
Office of Naval Research
800 N. Quincy St.
Code 125
Arlington, VA 22217-5000

Dr. Cary Czichon
Intelligent Instructional Sy
Texas Instruments AI Lab
P.O. Box 660245
Dallas, TX 75266

Bryan Dallman
AFHRL/LRT
Lowry AFB, CO 80230

LT John Deaton
ONR Code 125
800 N. Quincy Street
Arlington, VA 22217-5000

Dr. Natalie Dehn
Department of Computer and
Information Science
University of Oregon
Eugene, OR 97403

Dr. Gerald F. DeJong
Artificial Intelligence Grou
Coordinated Science Laborato
University of Illinois
Urbana, IL 61801

Goery Delacote
Directeur de L'informatique
Scientifique et Technique
CNRS
15, Quai Anatole France
75700 Paris FRANCE

Mr. Robert Denton
AFMPC/MPCYPR
Randolph AFB, TX 78150

Mr. Paul DiRenzo
Commandant of the Marine Corps
Code LBC-4
Washington, DC 20380

Dr. R. K. Dismukes
Associate Director for Life Sciences
AFOSR
Bolling AFB
Washington, DC 20332

Defense Technical
Information Center
Cameron Station, Bldg 5
Alexandria, VA 22314
Attn: TC
(12 Copies)

Dr. Thomas M. Duffy
Communications Design Center
Carnegie-Mellon University
Schenley Park
Pittsburgh, PA 15213

Barbara Eason
Military Educator's
Resource Network
InterAmerica Research Associates
1555 Wilson Blvd
Arlington, VA 22209

Edward E. Eddowes
CNATRA N301
Naval Air Station
Corpus Christi, TX 78419

Dr. John Ellis
Navy Personnel R&D Center
San Diego, CA 92252

Dr. Richard Elster
Deputy Assistant Secretary
of the Navy (Manpower)
OASN (M&RA)
Department of the Navy
Washington, DC 20350-1000

Dr. Susan Embretson
University of Kansas
Psychology Department
426 Fraser
Lawrence, KS 66045

Dr. Randy Engle
Department of Psychology
University of South Carolina
Columbia, SC 29208

Lt. Col Rich Entlich
HQ, Department of the Army
OCSA(DACS-DPM)
Washington, DC 20310

Dr. Susan Epstein
Hunter College
144 S. Mountain Avenue
Montclair, NJ 07042

Dr. William Epstein
University of Wisconsin
W. J. Brogden Psychology Bld
1202 W. Johnson Street
Madison, WI 53706

ERIC Facility-Acquisitions
4833 Rugby Avenue
Bethesda, MD 20014

Dr. K. Anders Ericsson
University of Colorado
Department of Psychology
Boulder, CO 80309

Dr. Edward Esty
Department of Education, OER
Room 717D
1200 19th St., NW
Washington, DC 20208

Dr. Beatrice J. Farr
Army Research Institute
5001 Eisenhower Avenue
Alexandria, VA 22333

Dr. Marshall J. Farr
2520 North Vernon Street
Arlington, VA 22207

Dr. Pat Federico
Code 511
NPRDC
San Diego, CA 92152-6800

Dr. Jerome A. Feldman
University of Rochester
Computer Science Department
Rochester, NY 14627

Dr. Paul Feltovich
Southern Illinois University
School of Medicine
Medical Education Department
P.O. Box 3926
Springfield, IL 62708

Mr. Wallace Feurzeig
Educational Technology
Bolt Beranek & Newman
10 Moulton St.
Cambridge, MA 02238

Dr. Craig I. Fields
ARPA
1400 Wilson Blvd.
Arlington, VA 22209

Dr. Gerhard Fischer
University of Colorado
Department of Computer Science
Boulder, CO 80309

J. D. Fletcher
9931 Corsica Street
Vienna VA 22180

Dr. Linda Flower
Carnegie-Mellon University
Department of English
Pittsburgh, PA 15213

Dr. Kenneth D. Forbus
University of Illinois
Department of Computer Science
1304 West Springfield Avenue
Urbana, IL 61801

Dr. Barbara A. Fox
University of Colorado
Department of Linguistics
Boulder, CO 80309

Dr. Carl H. Frederiksen
McGill University
3700 McTavish Street
Montreal, Quebec H3A 1Y2
CANADA

Dr. John R. Frederiksen
Bolt Beranek & Newman
50 Moulton Street
Cambridge, MA 02138

Dr. Norman Frederiksen
Educational Testing Service
Princeton, NJ 08541

Dr. Alfred R. Fregly
AFOSR/NL
Bolling AFB, DC 20332

Dr. Bob Frey
Commandant (G-P-1/2)
USCG HQ
Washington, DC 20593

Dr. Alinda Friedman
Department of Psychology
University of Alberta
Edmonton, Alberta
CANADA T6G 2E9

Julie A. Gadsden
Information Technology
Applications Division
Admiralty Research Establish
Portsdown, Portsmouth PO6 4A
UNITED KINGDOM

Dr. R. Edward Geiselman
Department of Psychology
University of California
Los Angeles, CA 90024

Dr. Michael Genesereth
Stanford University
Computer Science Department
Stanford, CA 94305

Dr. Dedre Gentner
University of Illinois
Department of Psychology
603 E. Daniel St.
Champaign, IL 61820

Dr. Robert Glaser
Learning Research
& Development Center
University of Pittsburgh
3939 O'Hara Street
Pittsburgh, PA 15260

Dr. Arthur M. Glenberg
University of Wisconsin
W. J. Brogden Psychology Bldg.
1202 W. Johnson Street
Madison, WI 53706

Dr. Marvin D. Glock
13 Stone Hall
Cornell University
Ithaca, NY 14853

Dr. Gene L. Gloye
Office of Naval Research
Detachment
1030 E. Green Street
Pasadena, CA 91106-2485

Dr. Sam Glucksberg
Department of Psychology
Princeton University
Princeton, NJ 08540

Dr. Joseph Goguen
Computer Science Laboratory
SRI International
333 Ravenswood Avenue
Menlo Park, CA 94025

Dr. Sherrie Gott
AFHRL/MODJ
Brooks AFB, TX 78235

Jordan Grafman, Ph.D.
2021 Lyttonsville Road
Silver Spring, MD 20910

Dr. Richard H. Granger
Department of Computer Science
University of California, Irvine
Irvine, CA 92717

Dr. Wayne Gray
Army Research Institute
5001 Eisenhower Avenue
Alexandria, VA 22333

Dr. James G. Greeno
University of California
Berkeley, CA 94720

H. William Greenup
Education Advisor (E031)
Education Center, MCDEC
Quantico, VA 22134

Dipl. Pad. Michael W. Habon
Universitat Dusseldorf
Erziehungswissenschaftliches
Universitatsstr. 1
D-4000 Dusseldorf 1
WEST GERMANY

Prof. Edward Haertel
School of Education
Stanford University
Stanford, CA 94305

Dr. Henry M. Halff
Halff Resources, Inc.
4918 33rd Road, North
Arlington, VA 22207

Dr. Ronald K. Hambleton
Prof. of Education & Psychol
University of Massachusetts
at Amherst
Hills House
Amherst, MA 01003

Dr. Cheryl Hamel
NTSC
Orlando, FL 32813

Dr. Bruce W. Hamill
Johns Hopkins University
Applied Physics Laboratory
Johns Hopkins Road
Laurel, MD 20707

Dr. Ray Hannapel
Scientific and Engineering
Personnel and Education
National Science Foundation
Washington, DC 20550

Stevan Harnad
Editor, The Behavioral and
Brain Sciences
20 Nassau Street, Suite 240
Princeton, NJ 08540

Mr. William Hartung
PEAM Product Manager
Army Research Institute
5001 Eisenhower Avenue
Alexandria, VA 22333

Dr. Wayne Harvey
SRI International
333 Ravenswood Ave.
Room B-S324
Menlo Park, CA 94025

Dr. Reid Hastie
Northwestern University
Department of Psychology
Evanston, IL 60201

Prof. John R. Hayes
Carnegie-Mellon University
Department of Psychology
Schenley Park
Pittsburgh, PA 15213

Dr. Barbara Hayes-Roth
Department of Computer Science
Stanford University
Stanford, CA 95305

Dr. Frederick Hayes-Roth
Teknowledge
525 University Ave.
Palo Alto, CA 94301

Dr. Joan I. Heller
505 Haddon Road
Oakland, CA 94606

Dr. James Hendler
Dept. of Computer Science
University of Maryland
College Park, MD 20742

Dr. Jim Hollan
Intelligent Systems Group
Institute for
Cognitive Science (C-015)
UCSD
La Jolla, CA 92093

Dr. Melissa Holland
Army Research Institute for
Behavioral and Social Sci
5001 Eisenhower Avenue
Alexandria, VA 22333

Dr. Robert W. Holt
Department of Psychology
George Mason University
4400 University Drive
Fairfax, VA 22030

Dr. Keith Holyoak
University of Michigan
Human Performance Center
330 Packard Road
Ann Arbor, MI 48109

Prof. Lutz F. Hornke
Institut fur Psychologie
RWTH Aachen
Jaegerstrasse 17/19
D-5100 Aachen
WEST GERMANY

Mr. Dick Hoshaw
OP-135
Arlington Annex
Room 2834
Washington, DC 20350

Dr. James Howard
Dept. of Psychology
Human Performance Laboratory
Catholic University of
America
Washington, DC 20064

Dr. Steven Hunka
Department of Education
University of Alberta
Edmonton, Alberta
CANADA

Dr. Earl Hunt
Department of Psychology
University of Washington
Seattle, WA 98105

Dr. Ed Hutchins
Intelligent Systems Group
Institute for
Cognitive Science (C-015)
UCSD
La Jolla, CA 92093

Dr. Dillon Inouye
WICAT Education Institute
Provo, UT 84057

Dr. Alice Isen
Department of Psychology
University of Maryland
Catonsville, MD 21228

Dr. Zachary Jacobson
Bureau of Management Consulting
365 Laurier Avenue West
Ottawa, Ontario K1A 0S5
CANADA

Dr. Robert Jannarone
Department of Psychology
University of South Carolina
Columbia, SC 29208

Dr. Claude Janvier
Directeur, CIRADE
Universite' du Quebec a Montreal
Montreal, Quebec H3C 3P8
CANADA

COL Dennis W. Jarvi
Commander
AFHRL
Brooks AFB, TX 78235-5601

Dr. Robin Jeffries
Hewlett-Packard Laboratories
P.O. Box 10490
Palo Alto, CA 94303-0971

Dr. Robert Jernigan
Decision Resource Systems
5595 Vantage Point Road
Columbia, MD 21044

Margaret Jerome
c/o Dr. Peter Chandler
83, The Drive
Hove
Sussex
UNITED KINGDOM

Dr. Joseph E. Johnson
Assistant Dean for
Graduate Studies
College of Science and Mathe
University of South Carolina
Columbia, SC 29208

Dr. Richard Johnson
Boise State University
Simplot/Micron
Technology Center
Boise, ID 83725

CDR Tom Jones
ONR Code 125
800 N. Quincy Street
Arlington, VA 22217-5000

Dr. Douglas A. Jones
P.O. Box 6640
Lawrenceville
NJ 08648

Col. Dominique Jouslin de No
Etat-Major de l'Armee de Ter
Centre de Relations Humaines
3 Avenue Octave Greard
75007 Paris
FRANCE

Dr. Marcel Just
Carnegie-Mellon University
Department of Psychology
Schenley Park
Pittsburgh, PA 15213

Dr. Milton S. Katz
Army Research Institute
5001 Eisenhower Avenue
Alexandria, VA 22333

Dr. Scott Kelso
Haskins Laboratories,
270 Crown Street
New Haven, CT 06510

Dr. Dennis Kibler
University of California
Department of Information
and Computer Science
Irvine, CA 92717

Dr. David Kieras
University of Michigan
Technical Communication
College of Engineering
1223 E. Engineering Building
Ann Arbor, MI 48109

Dr. Peter Kincaid
Training Analysis
& Evaluation Group
Department of the Navy
Orlando, FL 32813

Dr. Walter Kintsch
Department of Psychology
University of Colorado
Campus Box 345
Boulder, CO 80302

Dr. Paula Kirk
Oakridge Associated Universities
University Programs Division
P.O. Box 117
Oakridge, TN 37831-0117

Dr. David Klahr
Carnegie-Mellon University
Department of Psychology
Schenley Park
Pittsburgh, PA 15213

Dr. Mazie Knerr
Program Manager
Training Research Division
HumRRO
1100 S. Washington
Alexandria, VA 22314

Dr. Janet L. Kolodner
Georgia Institute of Technology
School of Information
& Computer Science
Atlanta, GA 30332

Dr. Stephen Kosslyn
Harvard University
1236 William James Hall
33 Kirkland St.
Cambridge, MA 02138

Dr. Kenneth Kotovsky
Department of Psychology
Community College of
Allegheny County
800 Allegheny Avenue
Pittsburgh, PA 15233

Dr. David H. Krantz
2 Washington Square Village
Apt. # 15J
New York, NY 10012

Dr. Benjamin Kuipers
University of Texas at Austi
Department of Computer Scien
T.S. Painter Hall 3.28
Austin, Texas 78712

Dr. David R. Lambert
Naval Ocean Systems Center
Code 441T
271 Catalina Boulevard
San Diego, CA 92152-6800

Dr. Pat Langley
University of California
Department of Information
and Computer Science
Irvine, CA 92717

M. Diane Langston
Communications Design Center
Carnegie-Mellon University
Schenley Park
Pittsburgh, PA 15213

Dr. Jill Larkin
Carnegie-Mellon University
Department of Psychology
Pittsburgh, PA 15213

Dr. Robert Lawler
Information Sciences, FRL
GTE Laboratories, Inc.
40 Sylvan Road
Waltham, MA 02254

Dr. Paul E. Lehner
PAR Technology Corp.
7926 Jones Branch Drive
Suite 170
McLean, VA 22102

Dr. Alan M. Lesgold
Learning R&D Center
University of Pittsburgh
Pittsburgh, PA 15260

Dr. Alan Leshner
Deputy Division Director
Behavioral and Neural Sciences
National Science Foundation
1800 G Street
Washington, DC 20550

Dr. Jim Levin
University of California
Laboratory for Comparative
Human Cognition
D003A
La Jolla, CA 92093

Dr. John Levine
Learning R&D Center
University of Pittsburgh
Pittsburgh, PA 15260

Dr. Michael Levine
Educational Psychology
210 Education Bldg.
University of Illinois
Champaign, IL 61801

Dr. Charles Lewis
Faculteit Sociale Wetenschappen
Rijksuniversiteit Groningen
Oude Boteringestraat 23
9712GC Groningen
The NETHERLANDS

Dr. Clayton Lewis
University of Colorado
Department of Computer Science
Campus Box 430
Boulder, CO 80309

Library
Naval War College
Newport, RI 02940

Library
Naval Training Systems Cente
Orlando, FL 32813

Dr. Charlotte Linde
SRI International
333 Ravenswood Avenue
Menlo Park, CA 94025

Dr. Marcia C. Linn
Lawrence Hall of Science
University of California
Berkeley, CA 94720

Dr. Robert Linn
College of Education
University of Illinois
Urbana, IL 61801

Dr. Don Lyon
P. O. Box 44
Higley, AZ 85236

Dr. Jane Malin
Mail Code SR 111
NASA Johnson Space Center
Houston, TX 77058

Dr. William L. Maloy
Chief of Naval Education
and Training
Naval Air Station
Pensacola, FL 32508

Dr. Sandra P. Marshall
Dept. of Psychology
San Diego State University
San Diego, CA 92182

Dr. Manton M. Matthews
Department of Computer Scien
University of South Carolina
Columbia, SC 29208

Dr. Richard E. Mayer
Department of Psychology
University of California
Santa Barbara, CA 93106

Dr. James McBride
Psychological Corporation
c/o Harcourt, Brace,
Javanovich Inc.
1250 West 6th Street
San Diego, CA 92101

Dr. David J. McGuinness
Gallaudet College
800 Florida Avenue, N.E.
Washington, DC 20002

Dr. Kathleen McKeown
Columbia University
Department of Computer Science
New York, NY 10027

Dr. Joe McLachlan
Navy Personnel R&D Center
San Diego, CA 92152-6800

Dr. James McMichael
Assistant for MPT Research,
Development, and Studies
OP 01B7
Washington, DC 20370

Dr. Barbara Means
Human Resources
Research Organization
1100 South Washington
Alexandria, VA 22314

Dr. Douglas L. Medin
Department of Psychology
University of Illinois
603 E. Daniel Street
Champaign, IL 61820

Dr. Arthur Melmed
U. S. Department of Education
724 Brown
Washington, DC 20208

Dr. Jose Mestre
Department of Physics
Hasbrouck Laboratory
University of Massachusetts
Amherst, MA 01003

Dr. Al Meyrowitz
Office of Naval Research
Code 1133
800 N. Quincy
Arlington, VA 22217-5000

Dr. Ryszard S. Michalski
University of Illinois
Department of Computer Scien
1304 West Springfield Avenue
Urbana, IL 61801

Prof. D. Michie
The Turing Institute
36 North Hanover Street
Glasgow G1 2AD, Scotland
UNITED KINGDOM

Dr. George A. Miller
Department of Psychology
Green Hall
Princeton University
Princeton, NJ 08540

Dr. James R. Miller
MCC
9430 Research Blvd.
Echelon Building #1, Suite 2
Austin, TX 78759

Dr. Mark Miller
Computer*Thought Corporation
1721 West Plano Parkway
Plano, TX 75075

Dr. Andrew R. Molnar
Scientific and Engineering
Personnel and Education
National Science Foundation
Washington, DC 20550

Dr. William Montague
NPRDC Code 13
San Diego, CA 92152-6800

Dr. Tom Moran
Xerox PARC
3333 Coyote Hill Road
Palo Alto, CA 94304

Dr. Melvyn Moy
Navy Personnel R & D Center
San Diego, CA 92152-6800

Dr. Allen Munro
Behavioral Technology
Laboratories - USC
1845 S. Elena Ave., 4th Floor
Redondo Beach, CA 90277

Director,
Decision Support
Systems Division, NMPC
Naval Military Personnel Command
N-164
Washington, DC 20370

Director,
Distribution Department, NMPC
N-4
Washington, DC 20370

Director,
Overseas Duty Support
Program, NMPC
N-62
Washington, DC 20370

Head, HRM Operations Branch,
NMPC
N-62F
Washington, DC 20370

Assistant for Evaluation,
Analysis, and MIS, NMPC
N-6C
Washington, DC 20370

Spec. Asst. for Research, Experi-
mental & Academic Programs,
NTTC (Code 016)
NAS Memphis (75)
Millington, TN 38054

Director,
Research & Analysis Div.,
NAVCRUITCOM Code 22
4015 Wilson Blvd.
Arlington, VA 22203

Technical Director
Navy Health Research Center
P.O. Box 85122
San Diego, CA 92138

Leadership Management Educat
and Training Project Offi
Naval Medical Command
Code 05C
Washington, DC 20372

Technical Director,
Navy Health Research Ctr.
P.O. Box 85122
San Diego, CA 92138

Dr. T. Niblett
The Turing Institute
36 North Hanover Street
Glasgow G1 2AD, Scotland
UNITED KINGDOM

Dr. Richard E. Nisbett
University of Michigan
Institute for Social Researc
Room 5261
Ann Arbor, MI 48109

Dr. Mary Jo Nissen
University of Minnesota
N218 Elliott Hall
Minneapolis, MN 55455

Dr. Donald A. Norman
Institute for Cognitive Scie
University of California
La Jolla, CA 92093

Director, Training Laborator
NPRDC (Code 05)
San Diego, CA 92152-6800

Director, Manpower and Perso
Laboratory,
NPRDC (Code 06)
San Diego, CA 92152-6800

Director, Human Factors
& Organizational Systems
NPRDC (Code 07)
San Diego, CA 92152-6800

Fleet Support Office,
NPRDC (Code 301)
San Diego, CA 92152-6800

Library, NPRDC
Code P201L
San Diego, CA 92152-6800

Commanding Officer,
Naval Research Laboratory
Code 2627
Washington, DC 20390

Dr. Harold F. O'Neil, Jr.
School of Education - WPH 801
Department of Educational
Psychology & Technology
University of Southern California
Los Angeles, CA 90089-0031

Dr. Stellan Ohlsson
Learning R & D Center
University of Pittsburgh
3939 O'Hara Street
Pittsburgh, PA 15213

Director, Research Programs,
Office of Naval Research
800 North Quincy Street
Arlington, VA 22217-5000

Office of Naval Research,
Code 1133
800 N. Quincy Street
Arlington, VA 22217-5000

Office of Naval Research,
Code 1142
800 N. Quincy St.
Arlington, VA 22217-5000

Office of Naval Research,
Code 1142EP
800 N. Quincy Street
Arlington, VA 22217-5000

Office of Naval Research,
Code 1142PT
800 N. Quincy Street
Arlington, VA 22217-5000
(6 Copies)

Director, Technology Programs,
Office of Naval Research
Code 12
800 North Quincy Street
Arlington, VA 22217-5000

Special Assistant for Marine
Corps Matters,
ONR Code 00MC
800 N. Quincy St.
Arlington, VA 22217-5000

Assistant for Long Range
Requirements,
CNO Executive Panel
OP 00K
2000 North Beauregard Street
Alexandria, VA 22311

Assistant for MPT Research,
Development and Studies
OP 01B7
Washington, DC 20370

Dr. Judith Orasanu
Army Research Institute
5001 Eisenhower Avenue
Alexandria, VA 22333

Dr. Jesse Orlansky
Institute for Defense Analys
1801 N. Beauregard St.
Alexandria, VA 22311

Prof. Seymour Papert
20C-109
Massachusetts Institute
of Technology
Cambridge, MA 02139

CDR R. T. Parlette
Chief of Naval Operations
OP-112G
Washington, DC 20370-2000

Dr. James Paulson
Department of Psychology
Portland State University
P.O. Box 751
Portland, OR 97207

Dr. Douglas Pearse
DCIEM
Box 2000
Downsview, Ontario
CANADA

Dr. Virginia E. Pendergrass
Code 711
Naval Training Systems Center
Orlando, FL 32813-7100

Dr. Robert Penn
NPRDC
San Diego, CA 92152-6800

Dr. Nancy Pennington
University of Chicago
Graduate School of Business
1101 E. 58th St.
Chicago, IL 60637

Military Assistant for Training and
Personnel Technology,
OUSD (R & E)
Room 3D129, The Pentagon
Washington, DC 20301-3080

Dr. Ray Perez
ARI (PERI-II)
5001 Eisenhower Avenue
Alexandria, VA 2233

Dr. David N. Perkins
Educational Technology Center
337 Gutman Library
Appian Way
Cambridge, MA 02138

LCDR Frank C. Petho, MSC, USN
CNATRA Code N36, Bldg. 1
NAS
Corpus Christi, TX 78419

Administrative Sciences Department,
Naval Postgraduate School
Monterey, CA 93940

Department of Computer Science,
Naval Postgraduate School
Monterey, CA 93940

Department of Operations Research,
Naval Postgraduate School
Monterey, CA 93940

Dr. Tjeerd Plomp
Twente University of Technol
Department of Education
P.O. Box 217
7500 AE ENSCHEDE

THE NETHERLANDS

Dr. Martha Polson
Department of Psychology
Campus Box 346
University of Colorado
Boulder, CO 80309

Dr. Peter Polson
University of Colorado
Department of Psychology
Boulder, CO 80309

Dr. Steven E. Poltrock
MCC
9430 Research Blvd.
Echelon Bldg #1
Austin, TX 78759-6509

Dr. Harry E. Pople
University of Pittsburgh
Decision Systems Laboratory
1360 Scaife Hall
Pittsburgh, PA 15261

Dr. Mary C. Potter
Department of Psychology
MIT (E-10-032)
Cambridge, MA 02139

Dr. Joseph Psotka
ATTN: PERI-1C
Army Research Institute
5001 Eisenhower Ave.
Alexandria, VA 22333

Dr. Roy Rada
National Library of Medicine
Bethesda, MD 20894

Dr. Lynne Reder
Department of Psychology
Carnegie-Mellon University
Schenley Park
Pittsburgh, PA 15213

Brian Reiser
Department of Psychology
Princeton University
Princeton, NJ 08544

Dr. James A. Reggia
University of Maryland
School of Medicine
Department of Neurology
22 South Greene Street
Baltimore, MD 21201

CDR Karen Reider
Naval School of Health Sciences
National Naval Medical Center
Bldg. 141
Washington, DC 20814

Dr. Fred Reif
Physics Department
University of California
Berkeley, CA 94720

Dr. Lauren Resnick
Learning R & D Center
University of Pittsburgh
3939 O'Hara Street
Pittsburgh, PA 15213

Dr. Mary S. Riley
Program in Cognitive Science
Center for Human Information
Processing
University of California
La Jolla, CA 92093

William Rizzo
Code 712
Naval Training Systems Center
Orlando, FL 32813

Dr. Linda G. Roberts
Science, Education, and
Transportation Program
Office of Technology Assessment
Congress of the United States
Washington, DC 20510

Dr. Andrew M. Rose
American Institutes
for Research
1055 Thomas Jefferson St., NW
Washington, DC 20007

Dr. William B. Rouse
Search Technology, Inc.
25-b Technology Park/Atlanta
Norcross, GA 30092

Dr. Donald Rubin
Statistics Department
Science Center, Room 608
1 Oxford Street
Harvard University
Cambridge, MA 02138

Dr. David Rumelhart
Center for Human
Information Processing
Univ. of California
La Jolla, CA 92093

Ms. Riitta Ruotsalainen
General Headquarters
Training Section
Military Psychology Office
PL 919
SF-00101 Helsinki 10, FINLAN

Dr. Michael J. Samet
Perceptronics, Inc
6271 Variel Avenue
Woodland Hills, CA 91364

Dr. Roger Schank
Yale University
Computer Science Department
P.O. Box 2158
New Haven, CT 06520

Dr. W. L. Scherlis
Dept. of Computer Science
Carnegie-Mellon University
Schenley Park
Pittsburgh, PA 15213

Mrs. Birgitte Schneidelbach
Forsvarets Center for Leders
Christianshavns Voldgade 8
1424 Kobenhavn K
DENMARK

Dr. Walter Schneider
Learning R&D Center
University of Pittsburgh
3939 O'Hara Street
Pittsburgh, PA 15260

Dr. Alan H. Schoenfeld
University of California
Department of Education
Berkeley, CA 94720

Dr. Janet Schofield
Learning R&D Center
University of Pittsburgh
Pittsburgh, PA 15260

Dr. Marc Sebrechts
Department of Psychology
Wesleyan University
Middletown, CT 06475

Dr. Judith Segal
OERI
555 New Jersey Ave., NW
Washington, DC 20208

Dr. Robert J. Seidel
US Army Research Institute
5001 Eisenhower Ave.
Alexandria, VA 22333

Dr. Ramsay W. Selden
Assessment Center
CCSSO
Suite 379
400 N. Capitol, NW
Washington, DC 20001

Dr. W. Steve Sellman
OASD(MRA&L)
2B269 The Pentagon
Washington, DC 20301

Dr. Sylvia A. S. Shafto
OERI
555 New Jersey Ave., NW
Washington, DC 20208

Dr. T. B. Sheridan
Dept. of Mechanical Engineering
MIT
Cambridge, MA 02139

Dr. Ben Shneiderman
Dept. of Computer Science
University of Maryland
College Park, MD 20742

Dr. Ted Shortliffe
Computer Science Department
Stanford University
Stanford, CA 94305

Dr. Lee Shulman
Stanford University
1040 Cathcart Way
Stanford, CA 94305

Dr. Randall Shumaker
Naval Research Laboratory
Code 7510
4555 Overlook Avenue, S.W.
Washington, DC 20375-5000

Dr. Robert S. Siegler
Carnegie-Mellon University
Department of Psychology
Schenley Park
Pittsburgh, PA 15213

Dr. Herbert A. Simon
Department of Psychology
Carnegie-Mellon University
Schenley Park
Pittsburgh, PA 15213

LTCOL Robert Simpson
Defense Advanced Research
Projects Administration
1400 Wilson Blvd.
Arlington, VA 22209

Dr. Zita M Simutis
Instructional Technology
Systems Area
ARI
5001 Eisenhower Avenue
Alexandria, VA 22333

Dr. H. Wallace Sinaiko
Manpower Research
and Advisory Services
Smithsonian Institution
801 North Pitt Street
Alexandria VA 22314

Dr. Derek Sleeman
Stanford University
School of Education
Stanford, CA 94305

Dr. Charles F. Smith
North Carolina State Univers
Department of Statistics
Raleigh, NC 27695-8703

Dr. Edward E. Smith
Bolt Beranek & Newman, Inc.
50 Moulton Street
Cambridge, MA 02138

Dr. Linda B. Smith
Department of Psychology
Indiana University
Bloomington, IN 47405

Dr. Alfred F. Smode
Senior Scientist
Code 07A
Naval Training Systems Center
Orlando, FL 32813

Dr. Richard E. Snow
Department of Psychology
Stanford University
Stanford, CA 94306

Dr. Elliot Soloway
Yale University
Computer Science Department
P.O. Box 2158
New Haven, CT 06520

Dr. Richard Sorensen
Navy Personnel R&D Center
San Diego, CA 92152-6800

Dr. Kathryn T. Spoehr
Brown University
Department of Psychology
Providence, RI 02912

James J. Staszewski
Research Associate
Carnegie-Mellon University
Department of Psychology
Schenley Park
Pittsburgh, PA 15213

Dr. Marian Stearns
SRI International
333 Ravenswood Ave.
Room B-S324
Menlo Park, CA 94025

Dr. Robert Sternberg
Department of Psychology
Yale University
Box 11A, Yale Station
New Haven, CT 06520

Dr. Albert Stevens
Bolt Beranek & Newman, Inc.
10 Moulton St.
Cambridge, MA 02238

Dr. Paul J. Sticha
Senior Staff Scientist
Training Research Division
HumRRO
1100 S. Washington
Alexandria, VA 22314

Dr. Thomas Sticht
Navy Personnel R&D Center
San Diego, CA 92152-6800

Dr. David Stone
KAJ Software, Inc.
8420 East Shea Blvd.
Suite 161
Phoenix, AZ 85028

Dr Michael Suman, PD 303
Naval Training Systems Cente
Code N51, Comptroller
Orlando, FL 32813

Dr. Hariharan Swaminathan
Laboratory of Psychometric a
Evaluation Research
School of Education
University of Massachusetts
Amherst, MA 01003

Mr. Brad Sympson
Navy Personnel R&D Center
San Diego, CA 92152-6800

Dr. John Tangney
AFOSR/NL
Bolling AFB, DC 20332

Dr. Kikumi Tatsuoka
CERL
252 Engineering Research
Laboratory
Urbana, IL 61801

Dr. Martin M. Taylor
DCIEM
Box 2000
Downsview, Ontario
CANADA

Dr. Perry W. Thorndyke
FMC Corporation
Central Engineering Labs
1185 Coleman Avenue, Box 580
Santa Clara, CA 95052

Major Jack Thorpe
DARPA
1400 Wilson Blvd.
Arlington, VA 22209

Dr. Douglas Towne
Behavioral Technology Labs
1845 S. Elena Ave.
Redondo Beach, CA 90277

Dr. Amos Tversky
Stanford University
Dept. of Psychology
Stanford, CA 94305

Dr. James Tweeddale
Technical Director
Navy Personnel R&D Center
San Diego, CA 92152-6800

Dr. Paul Twohig
Army Research Institute
5001 Eisenhower Avenue
Alexandria, VA 22333

Headquarters, U. S. Marine Corps
Code MPI-20
Washington, DC 20380

Dr. Kurt Van Lehn
Department of Psychology
Carnegie-Mellon University
Schenley Park
Pittsburgh, PA 15213

Dr. Beth Warren
Bolt Beranek & Newman, Inc.
50 Moulton Street
Cambridge, MA 02138

Dr. David J. Weiss
N660 Elliott Hall
University of Minnesota
75 E. River Road
Minneapolis, MN 55455

Roger Weissinger-Baylon
Department of Administrative
Sciences
Naval Postgraduate School
Monterey, CA 93940

Dr. Donald Weitzman
MITRE
1820 Dolley Madison Blvd.
MacLean, VA 22102

Dr. Keith T. Wescourt
FMC Corporation
Central Engineering Labs
1185 Coleman Ave., Box 580
Santa Clara, CA 95052

Dr. Douglas Wetzel
Code 12
Navy Personnel R&D Center
San Diego, CA 92152-6800

Dr. Barbara White
Bolt Beranek & Newman, Inc.
10 Moulton Street
Cambridge, MA 02238

LCDR Cory deGroot Whitehead
Chief of Naval Operations
OP-112G1
Washington, DC 20370-2000

Dr. Michael Williams
IntelliCorp
1975 El Camino Real West
Mountain View, CA 94040-2216

Dr. Hilda Wing
Army Research Institute
5001 Eisenhower Ave.
Alexandria, VA 22333

A. E. Winterbauer
Research Associate
Electronics Division
Denver Research Institute
University Park
Denver, CO 80208-0454

Dr. Robert A. Wisher
U.S. Army Institute for the
Behavioral and Social Sciences
5001 Eisenhower Avenue
Alexandria, VA 22333

Dr. Martin F. Wiskoff
Navy Personnel R & D Center
San Diego, CA 92152-6800

Dr. Merlin C. Wittrock
Graduate School of Education
UCLA
Los Angeles, CA 90024

Mr. John H. Wolfe
Navy Personnel R&D Center
San Diego, CA 92152-6800

Dr. Wallace Wulfeck, III
Navy Personnel R&D Center
San Diego, CA 92152-6800

Dr. Joe Yasatuke
AFHRL/LRT
Lowry AFB, CO 80230

Dr. Masoud Yazdani
Dept. of Computer Science
University of Exeter
Exeter EX4 4QL
Devon, ENGLAND

Major Frank Yohannan, USMC
Headquarters, Marine Corps
(Code MPI-20)
Washington, DC 20380

Mr. Carl York
System Development Foundation
181 Lytton Avenue
Suite 210
Palo Alto, CA 94301

Dr. Joseph L. Young
Memory & Cognitive
Processes
National Science Foundation
Washington, DC 20550

Dr. Steven Zornetzer
Office of Naval Research
Code 1140
800 N. Quincy St.
Arlington, VA 22217-5000

Dr. Michael J. Zyda
Naval Postgraduate School
Code 52CK
Monterey, CA 93943-5100

END

JAN.

1988

DTIC